Confinement of Strongly Correlated Electrons in Oxide Artificial Structures

The quantum confinement of strongly correlated electrons in artificial structures provides an ideal platform for studying the behavior of correlated Fermi-liquid states in reduced dimensions. We have succeeded in creating a quantum well structure using a strongly correlated oxide of $SrVO_3$, and have for the first time observed the quantized states that demonstrate the confinement of strongly correlated electrons in the artificial oxide structure. By means of *in situ* angle-resolved photoemission spectroscopy, the unique behavior of the corralling strongly correlated electrons in two-dimensional space was revealed.

Depending on the number of conductive layers, layered strongly correlated oxides often exhibit unusual physical properties, such as high-temperature superconductivity in cuprates [1]. The properties originate from the stacked conductive layers sandwiched by block insulating layers, where strongly correlated electrons are confined in the two-dimensional space. The lowering of the dimensionality changes the interaction among the spin, charge, and orbital degrees of freedom. Thus, the close structural similarities of layered oxides to metallic quantum well (QW) structures have motivated researchers to create low-dimensional systems using artificial structures of a strongly correlated oxide. However, metallic QW states exhibiting dimensional controllability have not yet been achieved in oxide artificial structures.

We have for the first time succeeded in confining strongly correlated electrons in the artificial oxide structure based on $SrVO_3$ [2]. The critical factors for success with the quantum confinement were (1) precise growth control of a conductive oxide on an atomic scale using laser molecular beam epitaxy and (2) state-of-the-art angle-resolved photoemission (ARPES) spectroscopy using the synchrotron radiation available at the Photon Factory. Utilizing these growth and characterization techniques, we confirmed that strongly correlated electrons were confined in the quantum well of an artificial oxide structure.

Figure 1 shows the ARPES spectra for $SrVO_3$ ultrathin films varying in overlayer thickness obtained at the Γ and X points. The energy positions of the several quasiperiodic peaks evolved as a function of the overlayer thickness: with increasing thickness, one additional peak appears after another in the ARPES spectra at the Fermi level (E_F), and their peak positions shift to higher binding energies. The peak shift apparently converges at around 500 meV. The experimental data were adequately described by the usual phase-shift quantization rule [3], indicating the successful creation and control of metallic QW states in artificial oxide structures.

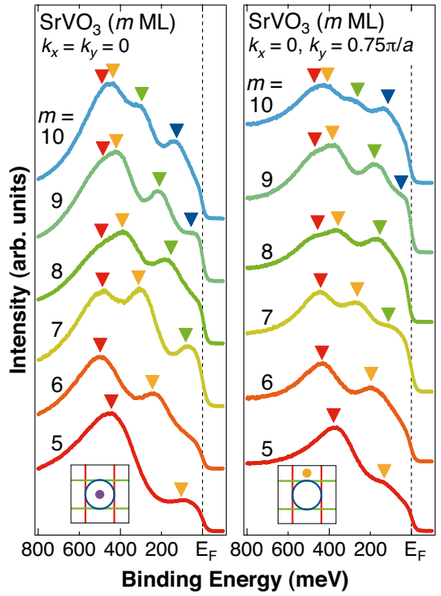

Figure 1
Thickness dependent ARPES spectra of $SrVO_3$ ultrathin films obtained at the Γ (left) and X (right) points. The peak structures derived from metallic QW states are marked by the triangle.

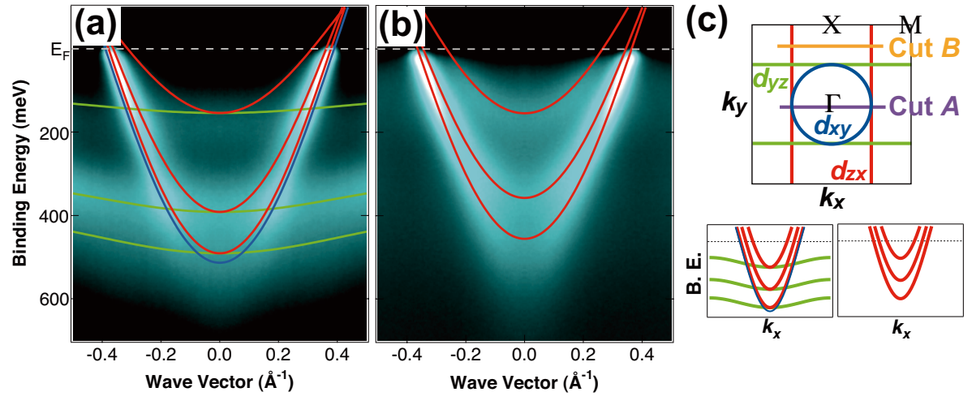

Figure 2
In-plane band dispersion of $SrVO_3$ (8 ML) ultrathin films along (a) Cut *A* and (b) Cut *B*. (c) Fermi surface cross section in ΓXM plane of bulk $SrVO_3$ and expected subband dispersions of $SrVO_3$ ultrathin films.

Furthermore, additional investigation revealed the existence of other interesting phenomena in the QW states (Fig. 2): 1) orbital-selective quantization originating from the anisotropic orbital character of the V 3*d* states and 2) unusual enhancement of the effective mass of the quantized electrons, reflecting complex interactions in the quantum well, neither of which has previously been reported in the conventional quantum well states in noble metals [3].

The orbital-selective quantization of the QW states is clearly observed in the in-plane band dispersion determined by ARPES. As can be seen in Fig. 2, a set of subbands is clearly observed corresponding to the different V 3*d* orbitals. Two types of subbands were observed for the band dispersion along cut *A* [Fig. 2(a)]; one is the parabolic band, which approaches and eventually crosses E_F with increasing distance from the Γ point, whereas the other is the nearly flat band. These two bands degenerate at the Γ point. In contrast, only parabolic subbands were observed along cut *B* [Fig. 2(b)]. In comparison to the tight-binding calculation, the flat bands seen only in Fig. 2(a) and the parabolic band seen in both cases originate from the quantized d_{yz} and d_{zx} states, respectively. On the other hand, the d_{xy} state remains unchanged because of its 2D character in the *xy* plane.

The unusual band renormalization is also seen in the in-plane band dispersion. The subband dispersion becomes considerably narrower (the effective mass of the subbands is considerably enhanced) as its bottom energy approaches E_F. The mass enhancement in the subbands is associated with strong interaction among V 3*d* electrons confined in the QW structures [2].

This successful creation and control of the metallic quantum well states in artificial structures of a strongly correlated oxide is a significant first step toward creating new physical phenomena and controlling the novel physical properties of strongly correlated oxides. The present results pave the way to a new world of “strongly correlated electronics”.

REFERENCES

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